

METHOD OF MANUFACTURING POROUS METAL PLATE-  
PLATES AND ~~ELECTRODE~~ ELECTRODES FOR ALKALINE  
STORAGE BATTERIES

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BACKGROUND OF THE INVENTION

10 1. Field of the Invention

The present invention relates to methods of manufacturing alkaline storage batteries, and more particularly to methods of manufacturing superior porous metal plates for positive electrodes.

15 2. Background Art

With the increasing trend for equipment to be portable and cordless, the need for small and light secondary batteries with high energy density for use as power sources for this type of equipment has grown. There is thus a strong and growing demand for inexpensive  
20 secondary batteries with high capacity. Accordingly, there is downward pressure on prices of alkaline storage batteries, typically nickel-hydrogen storage batteries and nickel-cadmium storage batteries, combined with calls for improved reliability.

The steps of manufacturing conventional alkaline storage batteries  
25 are described next. First, an electrically insulated separator is interposed between the positive and negative plates, mainly using nickel hydroxide as an active material, to create a laminated member. This

laminated member is wound spirally to create an electrode plate group. Then, the electrode plate group is housed in a metal battery case, and alkaline electrolyte solution is filled to a predetermined level. Lastly, the top of the battery case is sealed by a top cap which also acts as a positive or negative terminal.

The steps of manufacturing a conventional positive plate are described next. Active paste is made by mixing the active material mainly made of nickel hydroxide, water, and water-soluble binder. This active paste is impregnated in a porous nickel plate, and then dried. After drying, the porous nickel plate is pressed by passing it between small rollers to make the plate thickness uniform and enhance the density of the impregnated active material. Cracking inevitably occurs during winding in some of conventionally manufactured positive plates, with the risk of cracking rising as the battery capacity becomes greater.

To enable the battery to discharge a high current, the area of facing positive and negative plates need to be made as broad as possible during winding. But the broadening of the area causes increase of the volume of the core member. The Japanese Laid-open Patent No. H3-226969 shows how to suppress cracking which may occur while winding positive and negative plates, where a method of peeling is adopted in which the twisting direction of electrode plates becomes perpendicular to the deflating direction of pores during foaming.

The positive plate using a conventional material is compressed on an inner periphery, that is, to the winding core, but expanded on the outer periphery. This is the main cause of cracking on the outer periphery. In

particular, batteries with high electrical capacity have insufficient flexibility, increasing the risk of causing cracking. A cracked portion as occurred above penetrates through the separator, contacts the negative plate, and causes internal short-circuiting.

5           Moreover, foamed urethane, which is the base material for the porous positive plate, cannot be made thinner than 1 mm due to the performance limitations of current foam cutting machines and peeling machines. Accordingly, a core member having a two-dimensional structure such as a punch metal is required to be used in order to achieve  
10   a core thickness below 1 mm.

          If the active material is applied to this two-dimensional core member, a conductive net with the active material is not sufficiently established, causing difficulty in drawing out the required battery characteristics.

15           Furthermore, if a porous metal plate of 1 mm or thicker is rolled for thinning, the skeleton is broken, pores on the surface are blocked, or impregnation of mixed paste of active material is deteriorated in some cases.

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## SUMMARY OF THE INVENTION

          An object of the present invention is to eliminate the above disadvantages, and offer an electrode for high-capacity and high-power alkaline storage batteries, and a battery using this electrode. In  
25   particular, the present invention avoids the cost increase that would

otherwise occur due to increased core member volume, and also prevents a reduction of the occupied volume of active material, due to increased core member volume in the electrode, which would result in less battery capacity.

5           To achieve the above object, a method of manufacturing the electrode for alkaline storage batteries of the present invention includes a process of manufacturing a porous metal plate. In this process, an organic substance other than urethane is mixed in urethane sponge ( foamed urethane ), or urethane sponge is coated with polyethylene  
10   terephthalate before plating the urethane sponge.

Another method of manufacturing the porous metal plate for alkaline storage batteries includes the step of grinding the urethane sponge or the step of rolling the urethane sponge between a pair of roller presses in which at least the top or bottom roller is heated.

15           Mixed paste of active material mainly consisting of nickel hydroxide and water is impregnated in the porous metal plate manufactured through the above steps, and dried to manufacture the electrode of the present invention for alkaline storage batteries.

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## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a method of manufacturing a porous metal plate of the present invention for alkaline storage batteries

Fig. 2 is a chart comparing discharge ~~characteristic~~characteristics  
25   of batteries in Examples of the present invention and the prior art.

Fig. 3 is a schematic view of a conventional method of manufacturing a porous metal plate for alkaline storage batteries.

## DETAILED DESCRIPTION OF THE INVENTION

### 5 FIRST EMBODIMENT

A method of manufacturing a porous metal plate of the present invention for alkaline storage batteries includes the steps of: foaming urethane resin composition to make urethane sponge, coating the urethane sponge with polyethylene terephthalate, plating the urethane  
10 sponge with nickel, and firing the urethane sponge to remove organic materials.

Polyethylene terephthalate is preferably coated such that it accounts for 50 to 100% of the skeleton thickness of the urethane sponge. 'Skeleton' refers to the urethane resin surrounding each pore in the  
15 urethane sponge. 'Skeleton thickness' refers to the sectional area of the urethane resin perpendicular to the thickness direction of the urethane sponge. Accordingly, a thicker skeleton has larger sectional area of urethane resin, and contrarily, a smaller sectional area of pores. In other words, the proportion of the sectional area of urethane resin is large when  
20 the skeleton of the urethane sponge is thick.

The porous metal plate in the first exemplary embodiment is made of a foamed nickel matrix in which pores are connected three-dimensionally.

The thickness of the porous metal plate is preferably 0.2 to 0.8 mm.

Another method of manufacturing the porous metal plate in the first exemplary embodiment includes the step of mixing at least one of glycerin, polyethersulfone, and organopolysiloxane into the urethane sponge. Also in this case, the skeleton of the urethane sponge is  
5 thickened, and accordingly the volume ratio of the urethane resin becomes larger.

In the method of manufacturing an alkaline storage battery electrode in the first exemplary embodiment, an active material mainly consisting of nickel hydroxide is impregnated in the porous nickel plate  
10 manufactured using the method described above, after which the plate is dried.

The porous metal plate manufactured using the method in the first exemplary embodiment allows the use of the porous metal plate which is much thinner than a conventional porous metal plate. This enables the  
15 manufacture of electrodes whose nickel density is even lower than in the prior art. More specifically, the core member volume can be reduced to half from the conventional 400 g/m<sup>2</sup> to 200 g/m<sup>2</sup>. As a result, no cost increase results, even if the length of the electrode plate is made longer than in the prior art.

20 The following two disadvantages are suppressed by making an electrode plate group by spirally winding the positive plate described in the first exemplary embodiment, a negative plate, and a separator:

(1) Cracking mainly on the outer periphery of the positive plate during winding; and

(2) Internal short-circuiting caused by any burrs on the cut edge of the electrode plate penetrating the separator and contacting the negative plate.

The positive plate made of the porous metal plate of the present invention contributes to progress in increasing the capacity and power of alkaline storage batteries. The output characteristic improves with increased area of the positive plate and negative plate facing each other in the winding direction.

The first exemplary embodiment of the present invention is detailed with reference to examples below.

(Example 1)

The urethane sponge is made by adding a foaming agent to a solution of urethane resin composition. The urethane sponge sheet made is 1.6 mm thick having 55 consecutive pores per square inch.

Next, this urethane sponge sheet is immersed in a polyethylene terephthalate solution to coat the entire face, including inside the pores, of the urethane sponge sheet with polyethylene terephthalate. The coating thickness of polyethylene terephthalate is maintained at about 75% of the thickness of the urethane sponge skeleton.

This urethane sponge sheet is immersed in a palladium chloride solution as pretreatment, and electroless plating is applied to the urethane sponge sheet in a nickel-plating solution.

This urethane sponge sheet is then fired at 1000 °C in hydrogen gas to decompose and remove the organic substances to complete a porous nickel plate.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as a binder are added in a weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste, and these materials are mixed to create the active material paste.

5        This active material paste is impregnated in the above porous nickel plate and dried, and is then pressed to increase the impregnation density to create a positive plate ~~11~~ of width 35 mm, thickness 0.4 mm, and length 390 mm.

10       A separator is interposed as electrical insulation between this positive plate ~~11~~ and a negative plate of width 35 mm, thickness 0.2 mm, and length 495 mm; and these are spirally wound to create the electrode plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After  
15       injecting the alkaline electrolytic solution, the top of the battery case is sealed with a top cap which acts as a positive electrode terminal to complete a first nickel-hydrogen storage battery ~~110~~. This first storage battery ~~110~~ has a nominal capacity of 3000 mAh in the size HR26/47.

(Example 2)

20       Polyethersulfone resin particles are added to the urethane resin solution at the volume ratio of 20 : 100. Next, the foaming agent is added to this mixed solution for foaming and making urethane sponge 1.6 mm thick having 55 consecutive pores per square inch. This urethane sponge is then immersed in the palladium chloride solution as  
25       pretreatment, and electroless plating is applied to the urethane sponge in



the nickel-plating solution. The urethane sponge after nickel plating is fired at 1000 °C in hydrogen gas to complete the porous nickel plate.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. These materials are mixed to create the active material paste.

This active material paste is impregnated in the above porous nickel plate and dried, and is then pressed to increase the impregnation density to create a positive plate 12 of width 35 mm, thickness 0.4 mm, and length 390 mm.

A separator is interposed as electrical insulation between this positive plate ~~12~~ and a negative plate of width 35 mm, thickness 0.4 mm, and length 330 mm; and these are spirally wound to create the electrode plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is sealed with the top cap which acts as the positive electrode terminal to complete a second nickel-hydrogen storage battery-120. This second storage battery ~~120~~ has a nominal capacity of 3000 mAh in the size HR26/47.

(Comparison 1)

Next, the urethane sponge 1.6 mm thick having 55 consecutive pores per square inch is immersed in the palladium chloride solution as pretreatment, and is then plated in the nickel-plating solution. After

plating, this plated foamed-urethane resin is fired at 1000 °C in hydrogen gas to complete the porous nickel plate.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. These materials are mixed to create the active material paste. This active material paste is impregnated in the above porous nickel plate and dried, and is then pressed to increase the impregnation density to create a positive plate 13 of width 43.7 mm, thickness 0.8 mm, and length 75 mm.

A separator is interposed as electrical insulation between this positive plate ~~13~~ and a negative plate of width 43.7 mm, thickness 0.4 mm, and length 107 mm; and these are spirally wound to create the electrode plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is sealed with the top cap which acts as the positive electrode terminal to complete a third nickel-hydrogen storage battery-130. This storage battery ~~130~~ has a nominal capacity of 3000 mAh in the size HR26/47.

Then, 10,000 each of above the first, second and third batteries 110, 120-130 are made.

To confirm the leak resistance of the positive plate of Examples 1 and 2 and Comparison 1, the voltage of each of the first, second, and third batteries 110, 120, and 130 is measured after initial discharge and charge.

As judgment criteria for a voltage test, batteries having a terminal voltage between 1.20 and 1.35 V are regarded as non-defective.

All 10,000 of each of the first and second batteries ~~110 and 120~~ in the first exemplary embodiment are found to have a voltage between 1.25 and 1.28 V, thus demonstrating stable characteristics. Conversely, ~~in of~~ the 10,000 third batteries 130 in Comparison 1, six are found to have a voltage below 1.20 V, of which one battery was between 0.00 and 0.10 V.

Investigations made by taking apart the third batteries ~~130~~ with defective voltage reveal the occurrence of cracking on the outer periphery of the positive plate ~~13~~ or edge burr. This cracked or burred portion has penetrated through the separator and made contact with the negative plate, causing internal short-circuiting.

In this Comparison 1, the positive plate is compressed on the inner periphery to the winding core and expanded on the outer periphery when the positive plate is wound. Cracking occurs when the outer periphery of the positive plate expands due to insufficient flexibility of the positive plate. The cut burr at the edge occurs because the cutting teeth are usually difficult to enter in the thickness direction, and thus often the material is cut as the edge extends. In particular, since the cut skeleton is exposed randomly on the edge when a porous metal plate is used, a thicker plate is more likely to generate burrs. Accordingly, if the electrode plate can be made thinner, as in the first exemplary embodiment, the cutting teeth can enter uniformly, resulting in a smooth edge. Consequently, burrs are unlikely to occur.

## SECOND EMBODIMENT

Major steps in a method of manufacturing the porous metal plate in a second exemplary embodiment are described with reference to Fig. 1.

The method of manufacturing the porous metal plate of the  
 5 present invention includes:

- (a) foaming urethane resin composition to make urethane sponge (Step P01);
- (b) peeling the urethane sponge (Step P02);
- (c) plating the urethane sponge with nickel (Step P03);
- 10 (d) grinding the urethane sponge (Step P04); and
- (e) firing the urethane sponge to remove it (Step P05).

Furthermore,

- (f) mixed paste of active material mainly consisting of nickel hydroxide and water is impregnated in the porous nickel plate
- 15 manufactured using the method described above, after which the plate is dried to complete an alkaline storage battery electrode in the second exemplary embodiment.

The thickness of the urethane sponge is preferably made to be 1.4  
 to 2.0 mm in the above peeling step, and 0.5 to 1.0 mm in the grinding  
 20 step. The thickness of the porous metal plate is preferably 0.2 to 0.8 mm.

It is also preferable to cure or cross-link the urethane resin composition before foaming it in order to facilitate peeling and grinding. To cure the urethane resin composition, it is preferable to mix 2 to 4 parts by weight of epoxy resin to 15 parts by weight of urethane resin so as to  
 25 achieve a preferable degree of curing.

The sequence of Step P03 of plating and Step P04 of grinding can be reversed.

In Step P03, that of plating the urethane sponge with nickel, the urethane sponge is first immersed in metal catalyst solution and then the  
5 current is applied in the nickel solution.

In Step P02, that of peeling the urethane sponge, peeling is implemented by the foam cutting machine, which is a polyurethane processing machine, while the pore shape is sustained in the urethane sponge.

10 The above present invention has the following advantages over the conventional porous metal plate.

(1) An extremely thin porous metal plate can be made.

(2) The porous metal plate can survive the tension applied in the length direction when impregnating the active material paste.

15 (3) Production of electrodes is feasible even if the nickel density is below that in the prior art.

Accordingly, the core member volume can be reduced to half from the conventional 400 g/m<sup>2</sup> to 200 g/m<sup>2</sup>. The length of the electrode plate can thus be made longer for a reduced volume of the core member without  
20 increasing the cost.

The use of the positive plate made using the method in the second exemplary embodiment for the alkaline storage battery achieves the following advantageous effects compared to the use of the positive plate made using the conventional manufacturing method: (1) Reduces the  
25 occurrence of cracking which may occur mainly on the outer periphery of

the positive plate during winding; and (2) Reduces burrs which may occur at the cut edge of the positive plate. These effects significantly reduce the phenomenon of internal short-circuiting caused by the cracked positive plate or burr penetrating through the separator and contacting  
5 the negative electrode.

In general, the output characteristic improves with increased area of the positive plate and negative plate facing each other in the winding direction. Accordingly, the positive plate made of the above porous metal plate using the urethane sponge contributes to progress in increasing the  
10 capacity and power.

The second exemplary embodiment of the present invention is detailed with reference to examples below.

(Example 3)

Urethane sponge 1.6 mm thick having 55 consecutive pores per  
15 square inch is ground to 0.8 mm thick using a grinder. The ground foamed-urethane is immersed in the palladium chloride solution as pretreatment, and then electroplated in the nickel-plating solution. Nickel plating is applied such that the plating weight is 200 g/m<sup>2</sup> to the urethane sponge. This plated foamed-urethane is fired at 1000 °C in  
20 hydrogen gas to complete a porous nickel plate-201.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. These materials are mixed to create the active material paste.

This active material paste is impregnated in the above porous nickel plate ~~201~~ and dried, and is then pressed to increase the impregnation density to create a positive plate 21 of width 43.7 mm, thickness 0.2 mm, and length 143 mm in Example 3.

5        A separator is interposed as electrical insulation between this positive plate ~~21~~ and a negative plate of width 43.7 mm, thickness 0.2 mm, and length 204 mm; and these are spirally wound to create the electrode plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode  
10    plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is sealed with a top cap which acts as a positive electrode terminal to complete a fourth nickel-hydrogen storage battery 210. This storage battery 210 has a nominal capacity of 2000 mAh in the size AA.

15        (Example 4)

Urethane sponge 1.6 mm thick having 55 consecutive pores per square inch is immersed in the palladium chloride solution as pretreatment, and electroplated in nickel-plating solution such that the plating weight is 600 g/m<sup>2</sup>. This plated foamed-urethane is ground to 0.8  
20    mm thick and 300g/m<sup>2</sup> density using a grinder. After grinding, the urethane sponge is fired at 1000 °C in hydrogen gas to complete a porous nickel plate-~~202~~.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a

weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. These materials are mixed to create the active material paste.

This active material paste is impregnated in the above porous nickel plate 202 and dried, and is then pressed to increase the  
 5 impregnation density to create a positive plate 22 of width 43.7 mm, thickness 0.3 mm, and length 113 mm.

A separator is interposed as electrical insulation between this positive plate 22 and a negative plate of width 43.7 mm, thickness 0.2 mm, and length 204 mm; and these are spirally wound to create the electrode  
 10 plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is sealed with the top cap which acts as the positive electrode terminal to  
 15 complete a fifth nickel-hydrogen storage battery 220. This storage battery 220 has a nominal capacity of 2000 mAh in the size AA.

#### (Comparison 2)

A conventional method of manufacturing a porous metal plate in Comparison 2 shown in Fig. 3 is described next. Comparison 2 includes  
 20 Step P31 of foaming urethane resin composition to make urethane sponge, Step P32 of peeling the urethane sponge, Step P33 of nickel-plating the urethane sponge, and Step P34 of firing the urethane sponge to remove urethane resin.

Urethane sponge 1.6 mm thick having 55 consecutive pores per  
 25 square inch is made according to the above manufacturing steps. This



urethane sponge is immersed in the palladium chloride solution as pretreatment, and then electroplated in the nickel-plating solution. This urethane sponge is then fired at 1000 °C in hydrogen gas to complete ~~the~~ a porous nickel plate.

5           Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. These materials are mixed to create the active material paste.

10           This active material paste is impregnated in the above porous nickel plate ~~203~~ and dried, and is then pressed to increase the impregnation density to create a positive plate 23 of width 43.7 mm, thickness 0.8 mm, and length 75 mm.

15           A separator is interposed as electrical insulation between this positive plate ~~23~~ and a negative plate of width 43.7 mm, thickness 0.4 mm, and length 107 mm; and these are spirally wound to create the electrode plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is  
20           sealed with a top cap which acts as the positive electrode terminal to complete a sixth nickel-hydrogen storage battery 230. This storage battery 230 has a nominal capacity of 2000 mAh in the size AA.

          Next, 10,000 each of the above batteries 210, 220, and 230 are made.

The internal short-circuiting between the positive plate 21 or 22 in the second exemplary embodiment and the negative plate, and the positive plate 23 in the prior art and the negative plate is tested.

After the initial discharge and charge of batteries 210, 220, and 230 respectively, the batteries are left at 20 °C for 24 hours. Then, the voltage of 10,000 each of the batteries 210, 220, and 230 is measured. As judgment criteria for the test, batteries having a terminal voltage between 1.20 and 1.35 V are regarded as non-defective. All 10,000 of the batteries 210 and 220 in the second exemplary embodiment are found to have a voltage between 1.25 and 1.28 V. Conversely, five of the batteries 230 in Comparison 2 are found to have a voltage below the reference voltage 1.20 V, of which one battery has a voltage of 0.10 V.

Investigations made by taking apart the batteries 230 in Comparison 2 with defective voltage reveal the occurrence of cracking or edge burr. This cracked or burred portion has penetrated through the separator and made contact with the negative plate, causing internal short-circuiting.

In this Comparison 2, the positive plate 23 is compressed on the inner periphery of the winding core and expanded on the outer periphery when the positive plate 23 is wound. Cracking occurs when the outer periphery of the positive plate 23 expands due to insufficient flexibility of the positive plate. The cut burr at the edge occurs because the cutting teeth are usually difficult to enter in the thickness direction, and thus often the material is cut as the edge extends. In particular, since the cut skeleton is exposed randomly on the edge when a porous metal plate is

used, a thicker plate is more likely to generate burrs. Accordingly, if the electrode plate can be made thinner, as in the second exemplary embodiment, the cutting teeth can enter uniformly, resulting in a smooth edge. Consequently, burrs are unlikely to occur.

5           The discharge characteristic of batteries 210, 220, and 230 are shown in Fig. 2.

          In Fig. 2, the X axis is the discharge current in ampere (A), and the Y axis is discharge rate (%). The discharge rate is 100 % when discharge current is 0.2 A. The discharge rate up to a current of 10 A is  
10   measured. The results are shown in Fig. 2. It is apparent from Fig. 2 that storage battery 210 manufactured in Example 3 and storage battery 220 manufactured in Example 4 both show significant improvement in reduction of discharge rate at large currents compared to storage battery 230 manufactured in Comparison 2. Accordingly, it is apparent that the  
15   discharge characteristic at large currents is enhanced when the area of positive plate and negative plate facing each other is larger.

          Even if the facing area is small, the discharge rate characteristic can be maintained at almost the same level by increasing the weight of nickel plating per unit area of the porous metal plate.

20           It is also found that battery 210 described in Example 3 shows less increase in internal pressure during ~~charging~~charging, which is evidence that there is more allowance for the volume of components other than the electrode plate group in the battery case. Accordingly, for example, the positive plate containing more active material than that of the prior art  
25   can be used for further increasing the capacity of battery 210.

### THIRD EMBODIMENT

A method of manufacturing the porous metal plate in a third exemplary embodiment includes the following steps:

- 5           (a) peeling urethane sponge;
- (b) rolling the urethane sponge using a pair of roll presses whose top or bottom roller is at least heated;
- (c) nickel-plating the urethane sponge; and
- (d) firing the urethane sponge to remove urethane resin.

10           The sequence of step (b) of rolling and step (c) of plating can be reversed.

          The thickness of urethane sponge in the peeling step is preferably 1.4 to 2.0 mm, and the thickness of the urethane sponge in the step of rolling using the roll press is preferably 0.5 mm to 1.0 mm.

15           The thickness of the above porous nickel plate is preferably 0.2 mm to 0.8 mm.

          With respect to the roll press, the top and bottom rollers are heated between 200 and 400 °C so as to manufacture a uniform porous metal plate without uneven pores.

20           Alternatively, only one of the top and bottom rollers of the roll press is heated to between 200 and 400 °C. Rolling under this condition creates dense pores on one face of the porous metal plate contacting the heated roller, and relatively larger pores on the other face contacting the unheated roller.

Active material is impregnated in the plate as processed above to make the electrode. The face with a dense skeleton in the manufactured plate is placed outward, and the electrode is wound spirally. This is more likely than in the prior art to prevent cracks developing on the electrode during winding. Dense pores mean a low void rate on the porous nickel plate, and rough pores mean a high void rate.

The method of manufacturing the electrode for the alkaline storage battery in the third exemplary embodiment includes the step of manufacturing the aforementioned porous metal plate and the step of impregnating mixed paste of active material mainly consisting of nickel hydride and water in the plate and drying it.

The electrode for the alkaline storage battery described in the third exemplary embodiment is characterized by rolling the urethane sponge, using a heated roll press, to a predetermined thickness while preserving the foam skeleton of the urethane sponge.

This method enables the use of an extremely thin porous metal plate compared to the conventional porous metal plate. As a result, the plate survives the tension applied in the length direction when impregnating the active material mixed paste. Production of electrodes is thus made feasible even if the nickel density is lower than the prior art.

Accordingly, the core member volume can be reduced from the 400 g/m<sup>2</sup> used in the prior art to 200 g/m<sup>2</sup>. The length of the electrode plate can thus be made longer for a reduced volume of the core member without increasing the cost. This positive plate, the negative plate, and separator are combined and wound spirally to create the electrode plate

group. During winding, the occurrence of cracking which may occur mainly on the outer periphery of the positive plate and burrs which may occur at the cut edge of the positive plate can be suppressed. Accordingly, the phenomenon of internal short-circuiting caused by the cracked positive electrode or burr penetrating through the separator and contacting the negative electrode can be significantly reduced.

In general, the output characteristic improves as the area of the positive plate and negative plate facing each other in the winding direction increase. Accordingly, the positive plate manufactured using the above porous metal plate of the urethane sponge contributes significantly to higher capacity and power.

The third exemplary embodiment is detailed with reference to examples below.

(Example 5)

The top and bottom rollers of the roll press, consisting of a pair of top and bottom rollers, are heated to 250 °C. Urethane sponge 1.6 mm thick having 55 consecutive pores per square inch is rolled to a thickness of 0.8 mm by sandwiching urethane sponge by the top and bottom rollers. Rolled urethane sponge is immersed in the palladium chloride solution as pretreatment, and then electroplated in the nickel-plating solution. Plating volume is 200 g/m<sup>2</sup>. Then, plated foamed urethane is fired at 1000 °C in hydrogen gas to decompose and remove organic substances to complete a porous nickel plate.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a

weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. These materials are mixed to create the active material paste.

This active material paste is impregnated in the above porous nickel plate ~~301~~ and dried, and is then pressed to increase the  
 5 impregnation density and create a positive plate ~~31~~ of width 43.7 mm, thickness 0.2 mm, and length 143 mm.

A separator is interposed as electrical insulation between this positive plate ~~31~~ and a negative plate of width 43.7 mm, thickness 0.2 mm, and length 204 mm; and these are spirally wound to create the electrode  
 10 plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is sealed with a top cap which acts as a positive electrode terminal to  
 15 complete a seventh nickel-hydrogen storage battery ~~310~~. This seventh storage battery ~~310~~ has a nominal capacity of 2000 mAh in the size AA.

(Example 6)

The top and bottom rollers of the roll press, consisting of a pair of top and bottom rollers, are heated to 350 °C. Urethane sponge 1.6 mm  
 20 thick having 55 consecutive pores per square inch is immersed in the palladium chloride solution as pretreatment. This urethane sponge is then electroplated in the nickel-plating solution. The plating volume is 600 g/m<sup>2</sup>.

Plated foamed-urethane is sandwiched by the top and bottom  
 25 rollers of the roll press and the plated urethane sponge is rolled to a

thickness of 0.8 mm and density of 300 g/m<sup>2</sup>. This is fired at 1000 °C in hydrogen gas to complete a porous nickel plate ~~302~~.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a  
 5 weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. These materials are mixed to create the active material paste.

This active material paste is impregnated in the above porous nickel plate ~~302~~ and dried, and is then pressed to increase the  
 10 impregnation density to create a positive plate ~~32~~ of width 43.7 mm, thickness 0.3 mm, and length 113 mm.

A separator is interposed as electrical insulation between this positive plate ~~32~~ and a negative plate of width 43.7 mm, thickness 0.2 mm, and length 204 mm; and these are spirally wound to create the electrode plate group. The negative plate is made by applying hydrogen-storing  
 15 alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is sealed with a top cap which acts as a positive electrode terminal to complete an eighth nickel-hydrogen storage battery ~~320~~. This eighth  
 20 storage battery ~~320~~ made has a nominal capacity of 2000 mAh in the size AA.

### (Comparison 3)

Urethane sponge 1.6 mm thick having 55 consecutive pores per square inch is immersed in the palladium chloride solution as  
 25 pretreatment. This urethane sponge is then electroplated in the nickel-



plating solution. The plated urethane sponge is fired at 1000 °C in hydrogen gas to complete a porous nickel plate 303.

Active material paste is made in the following way. First, nickel hydroxide and carboxyl methyl cellulose as the binder are added in a weight ratio of 100 : 0.2. Then, water is added to 25 wt% of the entire paste. This active material paste is impregnated and dried, and is then pressed to increase the impregnation density to create a positive plate 33 of width 43.7 mm, thickness 0.8 mm, and length 75 mm.

A separator is interposed as electrical insulation between this positive plate 33 and a negative plate of width 43.7 mm, thickness 0.4 mm, and length 107 mm; and these are spirally wound to create the electrode plate group. The negative plate is made by applying hydrogen-storing alloy powder to the core member made of punch metal. The electrode plate group is housed in a battery case of nickel-plated iron. After injecting the alkaline electrolytic solution, the top of the battery case is sealed with a top cap which acts as a positive electrode terminal to complete a ninth nickel-hydrogen storage battery 330. This ninth storage battery 330 has a nominal capacity of 2000 mAh in the size AA.

Then, 10,000 each of the seventh, eighth, and ninth batteries 310, 320, 330 are manufactured.

The leak resistance of the seventh and eighth batteries 310 and 320 in Examples 5 and 6 and the ninth battery 330 in Comparison 3 is tested. After the initial discharge and charge of the seventh, eighth, and ninth batteries 310, 320, and 330, the voltage of 10,000 each of the seventh, eighth, and ninth batteries 310, 320, and 330 is measured. As

the judgment criteria for the test, batteries with a terminal voltage between 1.20 and 1.35 V are regarded as non-defective.

All 10,000 of each of the seventh and eighth batteries ~~310 and 320~~ in the third exemplary embodiment are found to have a voltage between  
5 1.25 and 1.28V. Conversely, six of the ninth batteries ~~330~~ in Comparison 3 are found to have a voltage below 1.20 V, of which one between 0.00 and 0.10 V.

Investigations made by taking apart the ninth batteries ~~330~~ in Comparison 3 with defective voltage reveal the occurrence of cracking on  
10 the outer periphery of the positive plate~~33~~. This cracked or burred portion has penetrated through the separator and made contact with the negative plate, causing internal short-circuiting. This difference in quality is caused for the same reason as described in the second exemplary embodiment.

15 As described above, the electrode of the present invention for alkaline storage batteries uses the porous metal plate for alkaline storage batteries manufactured using the method of the present invention. This prevents cracking on the positive plate during winding and also suppresses the occurrence of burrs at the edge.

20 Furthermore, the use of the porous metal plate of the present invention as the positive plate allows the manufacture of high capacity and high power alkaline storage batteries at low cost.